Internet of Things Education for MSc Study in Applied Mathematics and Computer Science

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***Abstract*—The observed digitalization of society and economy transforms the data from the following three "worlds" into digital format: a) the information world (accumulated human knowledge); b) the physical world (information from "things" around people); c) the social world (society and human expertise). Data fusion of these worlds is supported by the Internet of Things (IoT) technology. In this paper, we present an adapted MSc study program for students in Applied Mathematics and Computer Science in Petrozavodsk State University. We show how practical IoT problems become interesting research and development topics for educating the MSc students. The proposed adaptation can be further used for other basic MSc programs.**

I. Introduction

The observed digitalization of society and economy transforms the data from the following three "worlds" into digital format [1]: a) the information world (accumulated human knowledge); b) the physical world (information from "things" around people); c) the social world (society resources and human expertise). Data fusion of these worlds is supported by Internet of Things (IoT) [2]. Artificial intelligence (AI) supports information extraction from these big data sources and construction of digital services that act as information assistants in task solving by human [3]. Although many viewpoints on AI exist, in our IoT-related study we accent the AI learning role in human assistance by extending the cognitive function [4]. In the considered case, human is responsible for final decision making based on the automatically extracted information by AI methods.

As a curricular areas, IoT and AI now become a topical multidisciplinary subject, e.g., for smarter education [5] and digital platforms [6]. This stated the challenge to the educators around the globe enabling active curricular research. The demand motivated considerable effort of curricular researchers as well as universities and relative administrative boards. The effort is reflected in Computing Curricula 2020 (CC2020) [7], [8], which is a joint project launched by professional computing societies to examine the current curricular guidelines for academic degree programs in computing and provide a vision for the future of computing. In particular, CC2020 enlists Internet of Things as one of the Knowledge Areas.

On the other hand, the education system is relatively conservative due to its extremely high social importance and responsibility. Innovations in this sphere occur by many incremental advances and dynamic improvement while radical innovations could be disruptive. The curricular research in IoT and related AI technologies is still rather intensive and sustainable common practice of curricula development and adjustment in the area is yet to be developed.

Petrozavodsk state university (PetrSU, petrsu.ru) acquired considerable experience in the IoT and related areas [9]. In particular, the study course on Smart Spaces and many student projects on smart application development have been arranged since 2010. The students become involved into research projects for development and deployment of the emerging digital technologies in tight collaboration with research and industrial partners. Some examples of past projects one can find in [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24]. In total, more than 50 student pilots have been established, demonstrating the long history of fruitful collaboration between PetrSU and Association FRUCT (www.fruct.org).

Training high-quality specialists in the smart IoT and related AI technologies requires adaptation of the educational programs. In this paper, we present an adapted Master of Science program which softly revises already existed courses in respect to the emerging digital technologies. The adaptation is made within the basic Master of Science program "Applied Mathematics and Computer Science". As the key result, we offer 2 years full-time program, which includes seasonal schools in English.

The following concept of four thematic modules is considered to profile the IoT- and AI-related study disciplines.

Module 1. Mobile Technology and Ubiquitous Computing. Mastering in modern computing paradigms (e.g., cloud, fog, and edge computing).

Module 2. Big Data and Data Mining. Mastering in system monitoring, data collection, and information extraction (e.g., data fusion and knowledge reasoning).

Module 3. Smart Spaces. Mastering in system engineering for distributed resource sharing in edge computing environments (e.g., cooperative service construction).

Module 4. Virtual and Augmented Reality. Mastering in digital process virtualization (e.g., making a physical object interactive to the user).

An important property is the presence of the use cases connected with ongoing research and development projects. Those show both the new possibilities and open problems of applying IoT and AI to IoT applications. In particular, the MSc student project work is performed within the following IoT application directions (as already experienced cases for practical training):

- digital collaborative work environments with effective information exchange [15], [16], [17];
- services for cultural heritage studies and e-tourism [18], [20];
- mobile healthcare and wellbeing [19], [21];
- Industrial Internet (smart factory, Industry 4.0) [24].

The rest of the paper is organized as follows. Section II reviews recent work on IoT education in universities. Section III shows our motivation to choose “Applied Mathematics and Computer Science” as a basic MSc education program for IoT-and AI-focused studies. Section IV describes the overall structure of the proposed IoT-focused MSc study program and its four main modules. Section V presents examples of our IoT-oriented modifications of existing education courses for the MSc studies.

II. Internet of Things Education

Computing Curricula from joint activity of ACM and IEEE Computer Society is the widely accepted standard for higher education in information and communication technology (ICT). Now CC2020 [7], [8] is on under review phase before final publication. It will appear this year, replacing Computing Curricula 2005 [25]. CC2020 enlists “Internet of Things” as one of the Knowledge Areas. China National Higher Education Catalog enlisted “Internet of Things engineering” as one of the nine specific categories related to Computing among “Computer science and technology”, “Software engineering”, “Network engineering”, and several others.

Many universities introduce the elements of IoT technologies in their degree programs in the form of a single course, distant learning courses or short courses (e.g. summer/winter schools), professional training. A survey and comparison of the several sound approaches to the single course arrangements an interested reader could find in [26]. Another example is provided by Aalto University (Finland), where they teach students how industry can apply distributed ledger technologies (aka blockchains) within Industrial IoT [27].

Few educational institutions provide Master degree programs devoted to the Internet of Things specifically. One example is the 18 months program for MSc students in Internet of Things offered by EURECOM—a Graduate school and Research Centre in digital sciences located in the Sophia Antipolis technology park (French Riviera, http://www.eurecom.fr/en).

Many Universities offering IoT engineering studies place them as a trajectory within some MSc degree programs [28]. In particular, Lomonosov Moscow State University (Russia) offers IoT trajectory within Distributed Systems and Computer Networks MSc degree program. ITMO University in Saint-Petersburg (Russia) offers several MSc degree programs that include trajectory “Internet of Things and Cyber-Physical Services”. Several digital platforms are developed for IoT studies in universities, e.g., see [29], [30].

Universities and educators offering such programs publish corresponding research papers to familiarize educational and research communities with their motivation of the course/program structure and in some cases, teaching experiences and analysis of the teaching results [31]. Most researchers agree that IoT area bases on a combination of the elements from ‘classis’ computing area although the set of the disciplines is not yet coordinated. For instance, EURECOM states that Operating Systems and Security form IoT fundamentals though several other researchers emphasize the role of Computer Engineering and/or Data Analysis.

The role of soft skill and corresponding teaching methods is growing rapidly. The role of soft skills (or human skills) for IoT curricula is rather variable across the courses and curriculum offered. The dependence between knowledge, skills, and disposition (soft skills) is the subject to active research, e.g., see [32].

Therefore, we observe that teaching practice started from single and intensive courses is evolved currently to IoT trajectories within various basic MSc study programs. Although a popular option is to include IoT study as a trajectory into another program. The option biases the teaching process towards computer engineering, data communication, data analysis, digital economy, etc. [33]. An interesting case is proposed by the OLYMPUS online platform [34] that enables a group of learners to think more deeply about IoT products and their design decisions.

More sustainable teaching practice is needed to consider feedback from the industry, society, graduates, related administration boards, and curricular researchers. The feedback should be analyzed to achieve common patterns accepted by the educational community. Our view is that due to the highly expected demand (especially for Industrial IoT [27]), the education in the area moves toward the full-time programs with study courses on particular emerging technologies like IoT. Nevertheless, specific inter-technology modules and their relation are not agreed within educational community so far.

III. Background

PetrSU has experience in training graduates specialized in Computer Science, Information Technology, Applied Mathematics, Information Systems, and Software Engineering [35], [9]. The study programs have been continuously adapted and transformed in respect to latest progress in computing paradigms and digital technology. The university targets the following aims

- Support education in the areas of emerging technologies.
- Equip graduates for the future career.
- Provide foundation for their self-education abilities.
- Follow standards of the Ministry of Education of Russian Federation.
- Follow recommendation of the ACM SIGCSE expressed in the following documents [25], [36].
- Meet demands and expectations of the corresponding branches of the industry, society and administration.

Despite of substantial efforts that educational institutions make now to keep curricula as flexible as possible there are however certain limitations. The highest education system is one of the essential institutions that contributes considerably into sustainable social and industrial development. All changes should be discussed and approved by experts in the educational, industrial, and sometimes administrative communities. Such changes have to take into account many aspects, demands, and expectations. The social aspect is extremely important as well. New students of a University have certain expectation and vision of their prospect at least for the five-six or more years. They choose a particular program and do not expect it to change considerably after, e.g., seven of fifteen months. A university faces two conflicting challenges when choosing the strategy for programs adaptation

1) Follow agile and expanding set of the requirements to the learning outcomes.
2) Design MSc programs with the predictable outcome.

With the aim the Dept. of Computer Science uses approach which assumes introducing topical elements in the existing courses wherever it is possible. Our reasoning is that MSc student should not study just a number of techniques to solve a set of particular currently topical professional problems, but theories, methods and approaches these techniques are based upon. The essential of the MSc qualification is a graduate of considerable quality with a long-term career in the field of the emerging technologies and high professional productivity. Master program graduate in the computing disciplines is expected to become a lifelong learner with an ability of the smooth and rapid adaptation to innovation in an area a person chooses being a student.

While transforming the program educators and the teaching staff has to choose the parts to keep and the parts to introduce. According to the principle the basic approach here is to keep fundamental knowledge units which do not change or change slightly.

At the moment most graduates study Computing within two MSc programs. Those are "Applied Mathematics and Computer Science" (Russian state code is 01.04.02) and "Information Systems and Technologies" (Russian state code is 09.04.02). Note that the term "Computer Science" is used as "Informatics" across Russian Federation. Each MSc program takes 120 credit units (cu). However, IoT technologies mostly are based on the methods and approaches of Software Engineering, Data Communication, Distributed System, Algorithm theory (including parallel computations), Network Services, Embedded Systems and several other parts of the Computer Science set. All these disciplines are presented in the BSc and MSc degree programs for Applied Mathematics and Computer Science. On this basis we adapt a particular MSc subprogram "Technologies of the Internet of Things". Note that the adjacent areas Applied Mathematics and Computer Science both require thinking on the level of abstract concepts and formal constructions.

Applied Mathematics (essentially based on pure Mathematics) teaches a student to deal with the formal constructions and reasoning discipline. Through this besides knowledge of fundamental abstract consents and methods forms a set of hard skills important for all areas of Computing. Applied Mathematics methods form the basis of tComputer Science discipline. The latter in turn serves as a fundamental part of knowledge in Information Systems, Information Technology and Software Engineering. As a result, the graduate ability to formulate and to solve vast variety of complex problems obtains a solid foundation. Hence, we achieve one of the most important qualification properties of an expert. Respectively, due to the approach the program remains sustainable for the students, the educational community can predict learning outcome and the feedback the university gets from the industry and the administration of different levels helps to tune the programs if needed.

With this aim in mind, we have modified a series of courses which remain important and/or topical for the area by adding there several new modules. The set of the courses contains: Web Application Architecture and Frameworks, Multiprocessor and Parallel Computing, Techs for Developing Network Services, Capacity Planning, Networking Performance Analysis. Furthermore, the MSc program already includes the study course Smart Spaces, where the IoT role is essential. Additionally, selected topics can be used within the intensive courses (20 contact hours) for International schools (summer and winter, 4 in total).

IV. Studies Structure for "Technologies of the Internet of Things"

A. Basic Parts of the MSc program

The basic MSc program is "Applied Mathematics and Computer Science". It takes 120 cu and two years of studies. The subprogram "Technologies of the Internet of Things" is formed. The courses cover latest advances in IoT-related problems mathematical modeling, algorithms, and software engineering are applied for.

For the first year the program offers to the students 10 compulsory courses and 3 elective courses. Totally 6 elective courses are offered. For the second year the program offers 1 compulsory course and 3 elective courses. Totally 12 elective courses are offered within two years. The distribution is shown in Table I. The elective courses are summarized in Table II.

TABLE I. Applied Mathematics and Computer Science: studies structure

First year, Fall-Spring	
The Discipline	cu
Capacity Planning	4
Dynamic Systems	5
Pattern Recognition	5
Intellectual Spaces	5
SE Project I	4
Game theory and its Applications	3
Applied problems of the Optimal Theory	4
Human Skills Courses	15
Elective courses	7
Practice	8
Second year, Fall-Spring	
Stochastic Modeling in communication Networks	2
Elective courses	15
Practice	37

The Practice schedule includes activities for the students can acquire experience for the professional area. The latter includes participating in research, industrial projects, e.g. [16], [24], teaching, and scientific writing.

The presented structure supports soft skills. Those obtain special attention in the practice programs. Our view is that IoT-related topics can be introduced in courses form the block

TABLE II. ELECTIVE COURSES

First year, Fall-Spring	
Modeling Advances	
Random Processes	3
Symbolic Computations	2
Software Engineering and Design Advances	
Web Server Framework	3
Techs of Network Services Development	2
Multiprocessor Computing Systems	2
Web Clients Architecture Templates	2
Second year, Fall-Spring	
Modeling Advances	
Modern Control Systems	5
System Analysis for Modeling of the Soc.-Ec. Dynamics	5
Software Engineering and Design Advances	
Networking Performance Evaluation	5
Distributed Systems	5
Multiprocessor and Parallel Computing	5
Software Engineering Project	5

of Software Engineering and Design Advances block as well as in the practice schedule.

B. Basic Modules of IoT part

The main purpose of the new MSc program is to qualify graduates for developing and applying the digital technology, including IoT and AmI. The studies help them to become able to solve problems in design and research for emerging technologies of IT industry and Computing. The area of concern narrows the field down to the research and development of the semantic methods for creating AmI systems [1]. In such a system, the available resources are regularly monitored and used for decision making through participants interaction. This way, AI is applied for IoT-related problems.

The semantic methods support solving many practical problems in IoT environments as follows [24], [37].

1) To increase the performance of the data exchange between participants of an Intellectual space for a wide range of the mobile and peripheral Internet environments, mobile devices, and applications.
2) To provide methods (resource ranking algorithms) of selection and involvement of suitable and available resources for data processing and decision making on interaction control in the mobile and edge-centric IoT environments.
3) To develop software for different types of the mobile devices that will provide the growth of the interaction performance and quality for the participants of the smart space by using of the available resources of the mobile peripheral Internet environments.

Based on this support we formulate the four basic knowledge modules (KM) for IoT studies in the MSc program.

1) *Mobile Technology and Ubiquitous Computing*. Introduction to modern computing paradigms. Digital computing environments around a person: in everyday life and at work. Internet, Internet of Things, Internet of Everything. Cloud, fog, and edge-centric computing. Emergence of cyber-physical and socio-cyber-physical systems. Smart things and information services.
2) *Big Data and Data Mining*. Technologies for monitoring and data collection. Intelligent processing of multiple heterogeneous data sources. AI in the form of AmI, which helps human in the search and analysis of information. Information service as a recommendation. Final decision-making is by the human, not by a computer.
3) *Smart Spaces*. Shared use of computing environment resources. Examples of information services: 1) multimedia environments for people to work together; 2) cultural heritage studies and e-tourism services; 3) mobile healthcare and wellbeing; 4) Industrial IoT for planning and managing production processes.
4) *Virtual and Augmented Reality*. Virtualization of problem-solving processes for the needs of the digital economy and digital society. Multi-modal systems for digital interaction with humans. Personal mobile device as a key tool for delivering information services and making decisions by human.

The four modules cover the research and development problems related to Software Engineering and Design, Capacity Planning, Performance Evaluation, Distributed Systems Design, Parallel Computation, Networking Services. The appropriate study courses can be modified to include parts concerning IoT technologies and smart applications. Therefore, the MSc program adaptation is structured by the proposed modules. Table IV-B shows the reflection of the modules in the courses adapted within the IoT part.

TABLE III. REFLECTION OF THE MODULES IN STUDY COURSES

The Discipline	Modules covered
Networking Performance Evaluation	1-3
Distributed Systems	2-3
Multiprocessor and Parallel Computations	1-4
Software Engineering Project	2-3
Capacity Planning	1-3
Technologies for Network Services Development	1-4
Architecture and Frameworks for Web-Applications	2 1

V. CASE STUDY: ADAPTED COURSES

In the section we describe in detail how the principles and paradigms described and discussed above are realized in the particular courses of the IoT Master program developed. In particular every subsection that follows presents one of the modified courses. First a subsection briefly describes the course former content, then states our view of the relation between the discipline and IoT area. Next it presents IoT concepts and methods introduced into the course.

A. Capacity Planning

Capacity planning discipline is intended to familiarize the students with capacity planning methodology, to emphasize the importance of planning and the scientifically founded resource management. It underlines the dependence between the marketing policies and resources and namely IT system resources management for the commercial success of a company. Besides it lets students to try their theoretical knowledge of the modeling methods in attempt to apply the knowledge for practical purposes. The course consists of the three main units. Those are topical performance modeling methods, capacity planning methodology and applications of those methods for several areas namely: wireless data communication, ad hoc networks, Internet access providers and end-to-end network performance. Within the course the students make a project related to the capacity planning problem of IT subsystem for a particular company they know about, employed or planning to join/establish.

Since many IoT systems are sensitive to the performance and QoS issues [1] we extended the set of the applications considered in the course and offer IoT capacity planning problems as an applications area for capacity planning methods. After the modification the issues of cloud computation performance and intellectual spaces performance are included in the course. The smart spaces topic is based on the research presented in [1]. The research considers a service-oriented information sharing environments that could be utilized for deploying IoT applications with the dynamic location detection and context-available interaction of some physical objects [38], [39]. For instance, it could be a smart space deployed in the localized resource-restricted IoT environments. Resource restriction that typically exists on practice extremely increase the importance of the capacity planning process. An environment is associated with a certain location or room equipped with a set of devices. As a result, they form a smart space for the everyday life objects connected through traditional computers and through this become data processors and service constructors to their users, that use mobile devices for the interactions.

In the frame of the course we consider a request pool problem. Namely we consider the overall performance of the Semantic Information Broker (SIB), which provides information updates for individual mobile clients [23].

Each client accesses the information using Request–Response, Subscription–Notification and Update operations. The delegation of some part of the processing from the SIB to its clients can essentially reduce the SIB workload. The similar approach to the congestion control is widely applied in distributed systems [40], [41]. For instance, the approach proved its efficiency for the TCP protocol and some LAN MAC protocols. Here the individual mobile clients perform congestion control algorithms by using active control of the info. We consider adaptive strategy which in fact, could be considered as generalization of the additive–increase/multiplicative–decrease (AIMD) algorithm.

The strategy has the following form [42]. Let $i = 1, 2 \ldots$ be a sequence of the updates done by the client, t_i is time period between two consecutive updates $i-1$ and i, k_i is the number of losses during t_i. At the end of t_{i-1}, the client makes a decision about duration of the next t_i period using a function $t^i = g(t_{i-1}, k_{i-1})$.

In particular

$$t_i = \begin{cases} t_{j-1}/\alpha, & k_{j-1} > 0 \\ t_{i-1} + \delta & k_{i-1} = 0, \end{cases} \quad (1)$$

where $\alpha > 1$ stands for the decrease and $\delta > 0$. For the capacity planning process, we use the following results as a performance model

$$T = \mathsf{E}[X_n^*] \le \alpha \sqrt{\frac{2\delta}{\lambda^*(\alpha^2 - 1)}}, \quad (2)$$

where T is the expected length of t_i before a multiplicative decrease epoch.

$$K \approx \lambda T \le \lambda \sqrt{\frac{2\delta}{\lambda^*(\alpha^2 - 1)}}., \quad (3)$$

where K which is average number of losses between two multiplicative decrease epochs at X_n interval. The formulae are obtained in our previous works, e.g., see [23].

Following the capacity planning methodology we define the service level using the metrics above. For instance, one can consider.

- The interval between two consecutive active updates shouldn't exceed 5 sec (for guarantees of the fair information retrieval)
- The interval between two consecutive active updates shouldn't be less than 100 msec (for energy saving regime)
- The update loss rate shouldn't exceed 0.1% (for critical application).

Then we offer the students following or similar problems [42].

- Could the SIB support 100 more clients without significant service level degradation?
- What values of α and δ the system administrator should choose to satisfy service level requirements for the existed population of the clients?
- Could the smart space satisfy service level demand for the application critical to losses?
- Could the smart space satisfy service level demand for the application critical to delay?
- What are the best upgrade of the environment by the price-quality criterion.

The answer could be provided on the base of the smart space performance model and service levels requirements

More sophisticated version of the strategy (1) could be considered as well. The equation and its variants are offered as an advanced problem within the course or as a research problem.

As well we offer a set of capacity planning problems applicable for the powerful server (e.g., cloud computing). Here we use queuing performance models.

- How many queues a server needs to meet service level requirements for batch jobs?
- How many replicas of a database a server needs to meet service level requirements for interactive operation?
- How application can choose a cloud server that meets its requirements for delay, reliability, accessibility, etc.

B. Distributed Systems

Distributed System discipline belongs to the fundamental core of the modern Software Engineering. For the MSc program Applied Mathematics and Computer Science the course included the following chapters: General Overview, Communication, Processes, Entities Names, Synchronization, Fault Tolerance, Replication, Transactions. Practically all these topics concern all four KUs of the 'Technologies of the Internet of Things' program [38]. The course expansion is made in several important directions.

Traditionally communication and processes, including the issues of marshalling, demarchalling, proxies, the types of the behavior are considered through wired LAN networks. After modification the focus on the cloud, foggy and peripheral computing and its difference comparing to the so called 'traditional' Internet. Besides client-server architecture (which is still definitely topical) we consider public-subscribe architecture, its specialties and its role for IoT systems. The set of the case studies which are traditionally considered as well, e.g., distributed file system, document services and Web, we expand to present a part on the smart spaces based on the Smart M3 framework.

As a practical exercise we offer students problems connected with IoT environments. Those are following or similar

- Design a message for communication between SIB and a mobile client
- Propose synchronization algorithm for the public-subscribe architecture system.
- Design key processes for a cloud/peripheral computation system.

During the course the students perform a project. In its frame they design key elements of a distributed system within key IoT paradigms.

C. Multiprocessor and Parallel Computing

The course of multiprocessor and parallel computing initially focused on computational methods and methods of their parallel implementation. The course considered the set of general issues of the area, i.e., the architectures of the parallel computers, distributed operation systems, introduction to parallel algorithms and fundamentals of the parallel programming. The application considered were: cumbersome computation using cluster computers and parallel processing algorithms for the distributed systems. For instance, the distribution of processing efforts between a server and client devices.

Emerging technologies provide many modern services important both for industry and/or individual users but alongside they demand extensive computational resources. Multiprocessor systems and parallel computing provide powerful platform able to maintain intensive processing and hence all four KMs somehow involve elements of parallel processing.

Mobile Technologies and Ubiquitous Computing KM1 implies deployment of the cloud, foggy and peripheral systems. These apply to the technologies of the parallel algorithms and machine-oriented protocols. Big Data and Data Mining KM2 demands sophisticated algorithms and hence parallel processing as well. Smart Spaces KM3 provide a set of the network services and often need to process data concurrently. Virtual and Augmented Reality KM4 implements resource consuming algorithms and parallel computations could often improve their efficiency.

The course is extended by the following parts.

- Arrangements of the cloud, foggy and edge computing. The part considers organizational issues, the nodes architecture and methods for algorithms transformation to the parallel form, as well as the features of computing results acquisition and control.
- Basic methods and approaches to Big Data analysis. The part considers main problems and key approaches their solution. Also, it presents the parallel indexing, search and classification algorithms.
- Parallel computing in the heterogeneous networks. The part considers distinctive features of the heterogeneous networks and their examples. The algorithms of computations distribution across the network nodes are presented.
- Algorithms of video and audio data processing. The part provides a survey of video and audio data classification, search and analysis algorithms. As well it considers the design of parallel learning algorithms and parallel data processing.

Thereby after extension the course covers all four IoT related KMs of the MSc programs. After modification it presents state-of-the-art in the area training students to apply powerful multiprocessor computing facilities to the development of the modern services.

D. Technologies for Network Services Development

The course is one of the basic for the program and presents fundamentals of the distributed services engineering. Namely it considers services containerization and visualization, technologies and protocols of the services communication and the methods of the services implementation relying on the features of different programing languages. For the new MSc program 'Technologies of the Internet of Things' the course covers mainly two KMs. Those are Big Data and Data Mining and Smart Spaces [20], [21]. Human assistant services often rely on the results of Big Data analysis and hence the course should include the methods of the interaction between such services and assistant applications. Smart spaces are designed to provide information delivery services and hence they should be covered by the discipline as well.

The course is extended by the following parts.

- Network services and wireless data communication. The part considers design of the network services using wireless data communication, distinctive features of the wireless bearer, algorithms and protocols used in the networks with high delays and high error rate.
- Smart data processing services. The part considers the principles of autonomous services design, the algorithms of the intellectual data processing and ambient solutions inference.

- The design of the inter-service operation and communication. The part considers methods and algorithms of inter-operation between different interfaces.

As a learning outcome of the course the students are expected to acquire knowledge, skills and human skills on design and implementation of the modern socio-cyber-physical systems.

E. Networking Performance Evaluation

The course considers basic methods of the networking performance evaluation. Basically, it consists of three main parts. Those are performance data monitoring, processing of the data acquired, and performance evaluation and final conclusion. The monitoring part considers monitors classification, main features of every class, typical use cases. The data processing part considers general methods of the data processing, including popular statistic techniques, precision of the observation, error control and some others. The evaluation part presents common performance metrics, the methods of their estimation. Alongside it discusses tight connection between performance model used and monitoring specification.

Additionally, the students make the group project which involves full cycle of the performance evaluation activity for a networking service or an application they choose.

So far, the course could be extended to cover mostly three KMs. Those are Mobile Technologies and Ubiquitous Computing KM1, Big Data and Data Mining KM2 and Smart Spaces KM3. The students can choose the performance evaluation project for any of these KMs and/or their combination, e.g., performance of a smart space application through wireless network.

The course is extended by the following parts.

- Performance metrics of IoT systems. The part considers distinctive features of the IoT performance, discusses performance metrics specific for IoT environments including smart spaces and distributed documents processing.
- Special monitoring and data observation techniques the IoT systems. The part considers motoring tools, regimes and overhead control methods.

Bellow we provide an example of the metrics set for an IoT environment (smart space). Let's consider the request pool problem described above. Here SIB provides for each client an access to the information updates using Request–Response, Subscription–Notification and Update operations. The clients may use a control strategy for different distributions of the updates loss number. For the environment we define two key performance metrics. These are the average number of losses k_{avg} and the average length of the delay interval between two consecutive checks t_{avg}:

$$k_{\text{avg}} = \frac{1}{n}\sum_{i=1}^{n} k_i \tag{4}$$

and

$$t_{\text{avg}} = \frac{1}{n}\sum_{i=1}^{n} t_i. \tag{5}$$

Here t_i is the delay between two consecutive information updates and k_i is the number of update losses during t_i. For the semi-adaptive strategies both values could be estimated by the performance model presented in Section V-A. As a project, students may gather statistics for the metrics and compare them with the experiments, try other implemented strategies or try to develop and evaluate their own strategy on the base of M3 platform. Notice that these metrics are different from those typically used for 'traditional' performance evaluation techniques and/or provided by popular monitors.

F. Web Server Framework and Web Clients Architecture Templates

The courses are designed for two terms and are developed to present most common methods, tool and practices of the application design on the Web platform. In the first term the platform architecture is considered as it is and its basic components are described. Much attention is focused on the modern stage of the HTTP protocol as well as on the tools and frameworks of the back-end development. The second term considers modern web-browsers development facilities and front-end programing (such as RIA) using HTML5 standard and JavaScript.

The extended course addresses to Mobile Technologies and Ubiquitous Computing KM1. The extension is mostly devoted to 'Web of Things' paradigm. The latter is based on the existing standards and architectures of web applications. It is designed to simplify integration of the systems and applications by using common applications level communication protocol and architectures (in particular REST). The course schedules more time for Web API design and considers its applications using IoT services. The course considers the methods to increase back-end efficiency since the embedded systems resources are scarce.

VI. Conclusion

This paper presented a modification of the MSc study program for students in "Applied Mathematics and Computer Science" in Petrozavodsk State University. The variant is based on our concept of four thematic modules that profile several existing IoT- and AI-related study courses. The study program is based on practical IoT problems which we meet in our joint activity with academical and industry partners. We show how the latest IoT-related problems become interesting topics for both basic research and applied development. Problem solving that can be effectively used for educating applied mathematicians and programmers. We expect that similar approach can be used for other basic MSc study programs, including education for hardware, software, and information engineers.

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REFERENCES

[1] D. Korzun, E. Balandina, A. Kashevnik, S. Balandin, and F. Viola, *Ambient Intelligence Services in IoT Environments: Emerging Research and Opportunities*. IGI Global, 2019.

[2] L. Atzori, A. Iera, and G. Morabito, "From "smart objects" to "social objects": The next evolutionary step of the internet of things," *IEEE Communications Magazine*, vol. 52, no. 1, pp. 97–105, Jan. 2014.

[3] J. Augusto, V. Callaghan, D. Cook, A. Kameas, and I. Satoh, "Intelligent environments: a manifesto," *Human-centric Computing and Information Sciences*, vol. 3, no. 1, pp. 1–18, 2013.

[4] F. Piccialli, G. Casolla, S. Cuomo, F. Giampaolo, and V. S. di Cola, "Decision making in iot environment through unsupervised learning," *IEEE Intelligent Systems*, vol. 35, no. 1, pp. 27–35, 2020.

[5] M. Kassab, J. DeFranco, and J. Voas, "Smarter education," *IT Professional*, vol. 20, no. 5, pp. 20–24, 2018.

[6] J. Autiosalo, "Platform for industrial internet and digital twin focused education, research, and innovation: Ilmatar the overhead crane," in *2018 IEEE 4th World Forum on Internet of Things (WF-IoT)*, 2018, pp. 241–244.

[7] J. Impagliazzo and A. N. Pears, "The CC2020 project — computing curricula guidelines for the 2020s," in *2018 IEEE Global Engineering Education Conference (EDUCON)*, 2018, pp. 2021–2024.

[8] A. Clear, A. S. Parrish, J. Impagliazzo, and M. Zhang, "Computing Curricula 2020: introduction and community engagement," in *Proceedings of the 50th ACM Technical Symposium on Computer Science Education (SIGCSE '19)*. Association for Computing Machinery, 2019, pp. 653–654.

[9] A. Voronin, I. Bogoiavlenskii, and V. Kuznetsov, "Perspectives on the emergence of computing programs propelled by local industry in russia," *ACM Inroads*, vol. 6, no. 4, pp. 41–51, Nov. 2015.

[10] A. Samoryadova, I. Galov, P. Borovinskiy, K. Kulakov, and D. Korzun, "M3-weather: A Smart-M3 world-weather application for mobile users," in *Proc. 8th Conf. of Open Innovations Framework Program FRUCT*, S. Balandin and A. Ovchinnikov, Eds. SUAI, Nov. 2010, pp. 160–166.

[11] D. Zaiceva, I. Galov, and D. Korzun, "A blogging application for smart spaces," in *Proc. 9th Conf. of Open Innovations Framework Program FRUCT and 1st Regional MeeGo Summit Russia–Finland*, S. Balandin and A. Ovchinnikov, Eds. SUAI, Apr. 2011, pp. 154–163.

[12] A. A. Lomov and D. G. Korzun, "Subscription operation in Smart-M3," in *Proc. 10th Conf. of Open Innovations Association FRUCT and 2nd Finnish–Russian Mobile Linux Summit*, S. Balandin and A. Ovchinnikov, Eds. SUAI, Nov 2011, pp. 83–94.

[13] P. Vanag and D. Korzun, "SmartSlog knowledge patterns: Initial experimental performance evaluation," in *Proc. 11th Conf. of Open Innovations Association FRUCT and Seminar on e-Tourism*, S. Balandin and A. Ovchinnikov, Eds. SUAI, Apr. 2012, pp. 176–180.

[14] R. Kadirov, E. Cvetkov, and D. Korzun, "Sensors in a Smart Room: Preliminary study," in *Proc. 12th Conf. of Open Innovations Association FRUCT and Seminar on e-Tourism*, S. Balandin and A. Ovchinnikov, Eds. SUAI, Nov. 2012, pp. 37–42.

[15] A. Vdovenko, S. Marchenkov, and D. Korzun, "Mobile multi-service smart room client: Initial study for multi-platform development," in *Proc. 13th Conf. of Open Innovations Association FRUCT and 2nd Seminar on e-Tourism for Karelia and Oulu Region*, S. Balandin and U. Trifonova, Eds. SUAI, Apr 2013, pp. 143–152.

[16] D. Korzun, I. Galov, and S. Balandin, "Development of smart room services on top of Smart-M3," in *Proc. 14th Conf. of Open Innovations Association FRUCT*, S. Balandin and U. Trifonova, Eds. SUAI, Nov 2013, pp. 37–44.

[17] S. Marchenkov and D. Korzun, "User presence detection based on tracking network activity in smartroom," in *Proc. 16th Conf. of Open Innovations Association FRUCT*, Oct. 2014, pp. 45–50.

[18] K. Kulakov, O. Petrina, D. Korzun, and A. Varfolomeev, "Towards an understanding of smart service: The case study for cultural heritage e-tourism," in *Proc. 18th Conf. Open Innovations Framework Program FRUCT*. ITMO University, Apr. 2016, pp. 145–152.

[19] A. V. Borodin and Y. V. Zavyalova, "An ontology-based semantic design of the survey questionnaires," in *Proc. 19th Conf. Open Innovations Association FRUCT*, S. Balandin and T. Tyutina, Eds., Nov. 2016, pp. 10–15.

[20] O. Petrina, V. Volokhova, Y. Svetlana, A. Varfolomeyev, and D. Korzun, "On semantic network design for a smart museum of everyday life history," in *Proc. 20th Conf. Open Innovations Framework Program FRUCT*, Apr 2017, pp. 676–680.

[21] A. Meigal, K. Prokhorov, N. Bazhenov, L. Gerasimova-Meigal, and D. Korzun, "Towards a personal at-home lab for motion video tracking in patients with Parkinson's disease," in *Proc. 21st Conf. Open Innovations Association FRUCT*, Nov. 2017, pp. 231–237.

[22] H. Purohit, D. Korzun, A. Shabaev, and A. Voronin, "Data interleaving for congestion reduction in mobile traffic transmission," in *Proc. 22nd Conf. Open Innovations Association FRUCT*, May 2018, pp. 211–216.

[23] O. Bogoiavlenskaia, D. Korzun, and K. Kulakov, "Random backoff for active control of information updates in smart spaces," in *Proc. 24th Conf. Open Innovations Association FRUCT*, Apr. 2019, pp. 47–53.

[24] N. Bazhenov and D. Korzun, "Event-driven video services for monitoring in edge-centric internet of things environments," in *Proc. 25th Conf. Open Innovations Association FRUCT*, Nov. 2019, pp. 47–56.

[25] "Computing Curricula 2005: the overview report (CC2005)," ACM, IEEE Computer Society, Tech. Rep., Mar. 2005. [Online]. Available: https://www.acm.org/binaries/content/assets/educationlcurricula-recommendations/cc2005-march06final.pdf

[26] D. Namiot and M. Sneps-Sneppe, "On internet of things and big data in university courses," *International Journal of Embedded and Real-Time Communication Systems (IJERTCS)*, vol. 8, no. 1, pp. 18–30, Jan. 2017.

[27] P. Nikander, J. Autiosalo, and S. Paavolainen, "Interledger for the industrial internet of things," in *2019 IEEE 17th International Conference on Industrial Informatics (INDIN)*, vol. 1, 2019, pp. 908–915.

[28] B. Burd, L. Barker, M. Divitini, F. A. F. Perez, I. Russell, B. Siever, and L. Tudor, "Courses, content, and tools for internet of things in computer science education," in *Proceedings of the 2017 ITiCSE Conference on Working Group Reports (ITiCSE-WGR '17)*. New York, NY, USA: Association for Computing Machinery, 2018, pp. 125–139.

[29] D. Dobrilovic and S. Zeljko, "Design of open-source platform for introducing internet of things in university curricula," in *2016 IEEE 11th International Symposium on Applied Computational Intelligence and Informatics (SACI)*, 2016, pp. 273–276.

[30] M. A. Akbar, M. M. Rashid, and A. H. Embong, "Technology based learning system in internet of things (iot) education," in *2018 7th International Conference on Computer and Communication Engineering (ICCCE)*, 2018, pp. 192–197.

[31] N. V. Papulovskaya, A. D. Tarasov, and D. A. Artemasov, "Future engineers: Education for the Internet of Things," in *2018 IV International Conference on Information Technologies in Engineering Education (Inforino)*, 2018, pp. 1–4.

[32] S. Frezza, M. Daniels, A. Pears, r. Cajander, V. Kann, A. Kapoor, R. McDermott, A.-K. Peters, M. Sabin, and C. Wallace, "Modelling competencies for computing education beyond 2020: A research based approach to defining competencies in the computing disciplines," in *Proceedings Companion of the 23rd Annual ACM Conference on Innovation and Technology in Computer Science Education (ITiCSE 2018)*. New York, NY, USA: Association for Computing Machinery, 2018, pp. 148–174.

[33] M. Khanafer and M. El-Abd, "Guidelines for teaching an introductory course on the internet of things," in *2019 IEEE Global Engineering Education Conference (EDUCON)*, 2019, pp. 1488–1492.

[34] A. Hussein, M. Barhamgi, M. Vecchio, and C. Perera, "Crowdsourced peer learning activity for internet of things education: A case study," *IEEE Internet of Things Magazine*, vol. 2, no. 3, pp. 26–31, 2019.

[35] I. A. Bogoiavlenskii, "Information and communication technology education based on the russian state educational standard of "applied mathematics and informatics"," in *Perspectives on Soviet and Russian Computing*, J. Impagliazzo and E. Proydakov, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 243–250.

[36] *Information Technology Curricula 2017: Curriculum Guidelines for Baccalaureate Degree Programs in Information Technology*. New York, NY, USA: Association for Computing Machinery, 2017.

[37] M. Gusev and S. Dustdar, "Going back to the roots–the evolution of

edge computing, an IoT perspective," *IEEE Internet Computing*, vol. 22, no. 2, pp. 5–15, Mar 2018.

[38] D. Korzun, S. Balandin, and A. Gurtov, "Deployment of Smart Spaces in Internet of Things: Overview of the design challenges," in *Internet of Things, Smart Spaces, and Next Generation Networking*, ser. Lecture Notes in Computer Science, S. Balandin, S. Andreev, and Y. Koucheryavy, Eds., vol. 8121. Springer, Aug. 2013, pp. 48–59.

[39] L. Roffia, F. Morandi, J. Kiljander, A. D. Elia, F. Vergari, F. Viola, L. Bononi, and T. Cinotti, "A semantic publish-subscribe architecture for the Internet of Things," *IEEE Internet of Things Journal*, vol. PP, no. 99, 2016.

[40] A. S. Tanenbaum and M. Van Steen, *Distributed systems: principles and paradigms*. Prentice-Hall, 2007.

[41] A. Lukyanenko, A. Gurtov, and E. Morozov, "An adaptive backoff protocol with markovian contention window control," *Communications in Statistics-Simulation and Computation*, vol. 41, no. 7, pp. 1093–1106, 2012.

[42] O. Bogoiavlenskaia, A. Vdovenko, D. Korzun, and A. Kashevnik, "Individual client strategies for active control of information-driven service construction in IoT-enabled smart spaces," *International Journal of Embedded and Real-Time Communication Systems (IJERTCS)*, vol. 10, no. 2, pp. 20–36, 2019.